TEXAS
San Angelo

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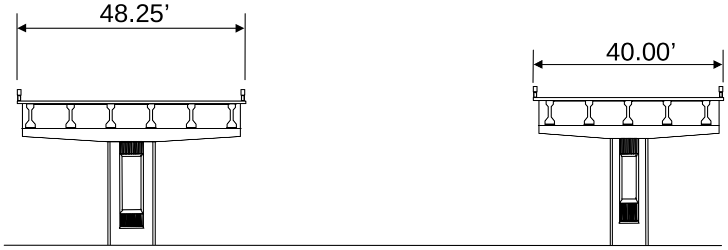
TEXAS
San Angelo

1. DESCRIPTION



Location:	U.S. Route 67 over North Concho River, U.S. Route 87, and South Orient Railroad, San Angelo, Texas
Open to Traffic:	January 1998
Environment:	Normal over a river, road, and railway
HPC Elements:	Eastbound – Columns, bent caps, girders, precast panels, and cast-in-place deck Westbound – Cast-in-place deck of Spans 1 through 5
Total Length:	Eastbound – 950 ft Westbound – 958 ft
Skew or Curve:	Spans at one end are skewed
Girder Type:	AASHTO Type IV for long spans Texas Type B for short spans
Girder Span Lengths:	Varies. See 10. DRAWINGS for details.
Girder Spacing:	Varies. See 10. DRAWINGS for details.

Girder Strand Grade:	270
Girder Strand Dia.:	Eastbound – Type IV uses 0.6 in, Type B uses 0.5 in Westbound – 0.5 in
Max. No. of Bottom Strands:	Eastbound – 84 based on the original design Westbound – 64
Deck Thickness:	7.5-in composite section with 3.5-in-thick cast-in-place concrete
Deck Panels	
—Length:	8 ft 0 in
—Thickness:	4-in-thick precast, prestressed
—Strand Grade:	270
—Strand Dia.:	3/8 in

2. BENEFITS OF HPC AND COSTS

A. Benefits of HPC

On the Eastbound bridge, which used HPC, eight spans were required for a total bridge length of 950 ft. On the Westbound bridge, which used conventional concrete, nine spans were required. Span 1 of both bridges was 131-ft long and had the same width. The Eastbound bridge utilized four girders at 11 ft 0 in spacing. The Westbound bridge utilized seven girders at 5.67-ft spacing. HPC was used in the decks to achieve high durability and low permeability.

B. Costs

Total Low Bid for Project:	\$11.65 million
HPC Eastbound:	\$42.03 ft^2 of deck area
HPC Westbound:	\$45.38 ft^2 of deck area
Girders:	\$115/linear ft for all types
Column Concrete:	HPC: \$385/yd^3
	Conventional: \$360/yd^3

3. STRUCTURAL DESIGN

The original design for the HPC beams in the main span of the Eastbound bridge utilized pretensioned girders with harped strands. The fabricator elected to use a two-stage fabrication process involving a combination of straight pretensioned strands and two post-tensioned tendons with a parabolic profile. Debonding of ten pretensioned strands in the bottom flange and the addition of six pretensioned strands in the top flange were used to control end stresses at transfer.

In this compilation, data labeled "original" means as originally designed whereas "modified" refers to the two-stage fabrication process.

Design Specifications:	AASHTO Standard Specifications for Highway Bridges, 1992, and Interim Specifications
Design Live Loads:	HS 20-44
Seismic Requirements:	None
Flexural Design Method:	AASHTO Standard Specifications with E_c = 6000 ksi for girders in Eastbound Spans 1 to 5
Maximum Compressive Strain:	—
Shear Design Method:	AASHTO Standard Specifications 9.20
Fatigue Design Method:	None
Lateral Stability Considerations:	Responsibility of fabricator. See 10. DRAWINGS for details.
Allowable Tensile Stress	
—Top of Girder at Release:	Eastbound: $10\sqrt{f'_{ci}}$ with bonded reinforcement
—Bottom of Girder after Losses:	Eastbound: $8\sqrt{f'_c}$
Prestress Loss:	Eastbound: 49,070 psi, Westbound: 47,910 psi
Method Used for Loss:	Time-step method using ADAPT-ABI including pre-release losses
Calculated Camber:	Eastbound: 1.63 to 3.16 in at release Westbound: 2.12 in at release
Concrete Cover	
—Girder:	Web: 1-1/8 in minimum to stirrups Bottom surface: 1 in
—Top of Deck:	2 in clear
—Bottom of Deck:	1-1/4 in clear 1-3/4 in cover to 3/8-in-diameter strands in panels
—Other Locations:	Not available
Properties of Reinforcing Steel	
—Girder:	Grade 60 uncoated
—Deck:	Grade 60 uncoated

Properties of Girder Strand	
—Grade and Type:	Grade 270, low relaxation
—Supplier:	Florida Wire and Cable
—Surface Condition:	
—Pattern:	Original: harp Modified: debonded bottom strands and bonded top strands with parabolic post-tensioning tendons
—Transfer Length:	Not available
—Development Length:	Not available

4. SPECIFIED ITEMS

A. Concrete Properties

The following classes of concrete were used on the superstructure of the San Angelo Bridge:

Direction	Span	Component		
		Precast Girders	Precast Deck Panels	CIP Deck
Eastbound	1-5	H(HPC)	H(HPC)	K(HPC)
	6-8	H	H(HPC)	K(HPC)
Westbound	1-5	H	H	S(HPC)
	6-9	H	H	S

	Precast Panels and Girders Eastbound Class H (HPC)	Cast-in-Place Deck Eastbound All Spans Class K (HPC)	Cast-in-Place Deck Westbound Spans 1 to 5 Class S (HPC)
Minimum Cementitious Materials Content:	564 lb/yd^3	611 lb/yd^3	611 lb/yd^3
Max. Water/Cementitious Materials Ratio:	0.49	0.44	0.44
Min. Percentage of Fly Ash:	20 with potentially reactive aggregates		
Max. Percentage of Fly Ash:	35 or 0 with Type IP and white portland cement		
Min. Percentage of Silica Fume:	Not specified	Not specified	Not specified
Max. Percentage of Silica Fume:	Not specified	Not specified	Not specified
Min. Percentage of GGBFS:	—	—	—
Max. Percentage of GGBFS:	50 or 0 with Type IP cement		
Maximum Aggregate Size:	1-1/2 in	1-1/2 in	3/4 in
Slump:	For $f'_c \geq 9000$ psi, slump may exceed 8 in when approved by the engineer	3-9	3-4
Air Content:	—	6	6
Compressive Strength:	Varies (See next table)	6000 psi at 28 days	4000 psi at 28 days

Member	Compressive Strength, psi		
	Eastbound Original	Eastbound Modified	Westbound
Girders at release	8900 to 10,800 (1)	8000 to 8100 (1)	4000 to 6600
	4000 to 6800 (2)	N/A	
Girders at 56 days	10,900 to 14,700 (1)	12,500 to 14,000 (1)	5000 to 8900 at 28 days
	5800 to 7800 (2)	N/A	
Panels at release	4000	N/A	4000
Panels at 28 days	6000	N/A	5000
Decks at 28 days	6000	N/A	4000
Bent caps at 28 days	8000	N/A	6000
Columns at 28 days	6000	N/A	3600

(1) Spans 1-5.
(2) Spans 6-8.

Chloride Permeability: (AASHTO T 277)	A guideline of 1500 coulombs at 56 days was used for all mix designs
ASR or DEF Prevention:	Minimum fly ash content of 20% required with potentially reactive aggregates
Freeze-Thaw Resistance:	—
Deicer Scaling:	—
Abrasion Resistance:	—
Other:	Strand pullout tests in conjunction with 14 beams

B. Specified QC Procedures

HPC Precast Production	
Curing:	Natural or steam
Internal Concrete Temperature:	$\geq$ 50 ^{o}F
Cylinder Curing:	Alongside member until release followed by ASTM standard curing
Cylinder size:	4x8 in for $f'_c \geq 9000$ psi
Cylinder Capping Procedure:	Unbonded capping systems capable of 15,000 psi or high-strength capping compound
Cylinder Testing Method:	Tex-418-A (Similar to AASHTO T 22)
Frequency of Testing:	Two sets of three cylinders per line of girders
Other QA/QC Requirements:	Strand pull out tests for girders
CIP Deck Construction	
Curing:	Wet mat curing for 10 days when fly ash is used or 8 days when fly ash is not used
Cylinder Curing:	AASHTO T 23 Standard Cure
Cylinder Size:	4x8 in
Flexural Strength:	Not specified
Other QA/QC Requirements:	—

5. CONCRETE MATERIALS

A. Concrete Mix Proportions for Girders

HPC mix proportions were developed by the research team for use by the fabricator.

	Eastbound Class H (HPC) Girders	Westbound Class H Girders
Cement Brand:	Capitol	Capitol
Cement Type:	III	III
Cement Composition:	See Page 57	See Page 57
Cement Fineness:	See Page 57	See Page 57
Cement Quantity:	671 lb/yd^3	526 lb/yd^3
GGBFS Brand:	—	—
GGBFS Quantity:	—	—
Fly Ash Brand:	Not available	Not available
Fly Ash Type:	C	C
Fly Ash Quantity:	312 lb/yd^3	196 lb/yd^3
Silica Fume Brand:	—	—
Silica Fume Quantity:	—	—
Fine Aggregate Type:	River sand	River sand
Fine Aggregate FM:	2.60	2.60
Fine Aggregate SG:	2.63	2.63
Fine Aggregate Quantity:	1062 lb/yd^3	1160 lb/yd^3
Coarse Aggregate, Max. Size:	0.5 in	0.75 in
Coarse Aggregate Type:	No. 7 crushed dolomitic limestone	No. 6 crushed river gravel
Coarse Aggregate SG:	2.68	2.63
Coarse Aggregate Quantity:	1863 lb/yd^3	1998 lb/yd^3
Water:	246 lb/yd^3	196 lb/yd^3
Water Reducer Brand:	—	—
Water Reducer Type:	—	—
Water Reducer Quantity (3):	—	—
High-Range Water-Reducer Brand:	—	—
High-Range Water-Reducer Type:	F	F
High-Range Water-Reducer Quantity (3):	200 fl oz/yd^3	159 fl oz/yd^3
Retarder Brand:	—	—
Retarder Type:	B	B
Retarder Quantity:	28 fl oz/yd^3	16 fl oz/yd^3
Corrosion Inhibitor Brand:	—	—
Corrosion Inhibitor Type:	—	—
Corrosion Inhibitor Quantity:	—	—

	Eastbound Class H (HPC) Girders	Westbound Class H Girders
Air Entrainment Brand:	—	—
Air Entrainment Type:	—	—
Air Entrainment Quantity:	None	None
Water/Cementitious Materials Ratio:	0.25	0.27

(3) Quantities varied depending on weather conditions.

B. Measured Properties of Concrete Mix for Girders

	Eastbound Class H (HPC)	Westbound Class H
Slump:	6-9 in	7-8 in
Air Content:	0.9%	0.9%
Unit Weight:	152.9 lb/ft^3	149.3 lb/ft^3

C. Concrete Mix Proportions for Precast Deck Panels

HPC mix proportions were developed by the researchers for use by the contractor.

	Eastbound Class H (HPC) Panels	Westbound Class H Panels
Cement Brand:	Capitol	Capitol
Cement Type:	III	III
Cement Composition:	See Page 57	See Page 57
Cement Fineness:	See Page 57	See Page 57
Cement Quantity:	658 lb/yd^3	564 lb/yd^3
GGBFS Brand:	—	—
GGBFS Quantity:	—	—
Fly Ash Brand:	—	—
Fly Ash Type:	—	—
Fly Ash Quantity:	—	—
Silica Fume Brand:	—	—
Silica Fume Quantity:	—	—
Fine Aggregate Type:	River sand	River sand
Fine Aggregate FM:	2.63	2.63
Fine Aggregate SG:	Not available	Not available
Fine Aggregate Quantity:	1355 lb/yd^3	1457 lb/yd^3
Coarse Aggregate, Max. Size:	1 in	1 in
Coarse Aggregate Type:	No. 5 crushed limestone	No. 5 crushed limestone
Coarse Aggregate SG:	Not available	Not available
Coarse Aggregate Quantity:	1844 lb/yd^3	1889 lb/yd^3
Water:	251 lb/yd^3	275 lb/yd^3
Water Reducer Brand:	—	—
Water Reducer Type:	D	D
Water Reducer Quantity:	300 fl oz/yd^3	257 fl oz/yd^3
High-Range Water-Reducer Brand:	—	—
High-Range Water-Reducer Type:	—	—
High-Range Water-Reducer Quantity:	—	—
Retarder Brand:	—	—
Retarder Type:	D	D
Retarder Quantity:	79 fl oz/yd^3	49 fl oz/yd^3
Corrosion Inhibitor Brand:	—	—
Corrosion Inhibitor Type:	—	—
Corrosion Inhibitor Quantity:	—	—
Air Entrainment Brand:	—	—
Air Entrainment Type:	—	—
Air Entrainment Quantity:	None	None
Water/Cementitious Materials Ratio:	0.38	0.49

D. Measured Properties of Concrete Mix for Precast Deck Panels

	Eastbound Class H (HPC) Panels	Westbound Class H Panels
Slump:	5-6 in	6-7 in
Air Content:	1.5%	1.5%
Unit Weight:	150.9 lb/ft^3	150.7 lb/ft^3
Chloride Permeability: (AASHTO T 277)	1980 coulombs at 56 days	3230 coulombs at 56 days

E. Concrete Mix Proportions for Cast-in-Place Concrete Deck

	Eastbound Bridge Class K (HPC)	Westbound Bridge Spans 1-5 Class S (HPC)	Westbound Bridge Spans 6-9 Class S
Cement Brand:	Lone Star	Lone Star	Lone Star
Cement Type:	II	II	II
Cement Composition:	Not available	Not available	Not available
Cement Fineness:	Not available	Not available	Not available
Cement Quantity:	490 lb/yd^3	427 lb/yd^3	611 lb/yd^3
GGBFS Brand:	—	—	—
GGBFS Quantity:	—	—	—
Fly Ash Brand:	—	—	—
Fly Ash Type:	C	C	—
Fly Ash Quantity:	210 lb/yd^3	184 lb/yd^3	—
Silica Fume Brand:	—	—	—
Silica Fume Quantity:	—	—	—
Fine Aggregate Type:	River sand	River sand	River sand
Fine Aggregate FM:	2.70	2.70	2.70
Fine Aggregate SG:	Not available	Not available	Not available
Fine Aggregate Quantity:	1365 lb/yd^3	1240 lb/yd^3	1243 lb/yd^3
Coarse Aggregate, Max. Size:	1.25 in	1.25 in	1.25 in
Coarse Aggregate Type:	No. 5 crushed river gravel	No. 5 crushed river gravel	No. 5 crushed river gravel
Coarse Aggregate SG:	Not available	Not available	Not available
Coarse Aggregate Quantity:	1900 lb/yd^3	1856 lb/yd^3	1856 lb/yd^3
Water:	219 lb/yd^3	258 lb/yd^3	258 lb/yd^3
Water Reducer Brand:	—	—	—
Water Reducer Type:	—	—	—
Water Reducer Quantity:	—	—	—
High-Range Water-Reducer Brand:	—	—	—
High-Range Water-Reducer Type:	F	—	—
High-Range Water-Reducer Quantity:	156 fl oz/yd^3	—	—
Retarder Brand:	—	Plastocrete 161R	Plastocrete 161R
Retarder Type:	B and D	B and D	B and D
Retarder Quantity:	28 fl oz/yd^3	26 fl oz/yd^3	26 fl oz/yd^3
Corrosion Inhibitor Brand:	—	—	—
Corrosion Inhibitor Type:	—	—	—
Corrosion Inhibitor Quantity:	—	—	—
Air Entrainment Brand:	—	—	—
Air Entrainment Type:	—	—	—
Air Entrainment Quantity:	3.1 fl oz/yd^3	3.1 fl oz/yd^3	3.1 fl oz/yd^3
Water/Cementitious Materials Ratio:	0.31	0.42	0.42

F. Measured Properties of Concrete Mix for Cast-in-Place Concrete Deck

	Eastbound Bridge Class K (HPC)	Westbound Bridge Spans 1-5 Class S (HPC)	Westbound Bridge Spans 6-9 Class S
Slump:	7-9 in	3-4 in	3-4 in
Air Content:	6%	6%	6%
Unit Weight:	149.4 lb/ft^3	145.3 lb/ft^3	145.6 lb/ft^3
Chloride Permeability: (AASHTO T 277)	690 coulombs at 56 days	1380 coulombs at 56 days	2490 coulombs at 56 days

6. CONCRETE MATERIAL PROPERTIES

A. Measured Properties from QC Tests of Production Concrete for Girders

Cement Composition:	Not available	
Actual Curing Procedure for Girders:	Natural heat of hydration Light steam on 2/25/97 only	
Curing Procedure for Cylinders:	Cured with member until release of strands followed by AASHTO T 23 Standard Curing	
	Eastbound Class H(HPC)	Westbound Class H
Slump:	See table below	7-8 in
Air Content:	2%	2%
Unit Weight:	153 lb/ft^3	149 lb/ft^3
Compressive Strength:	See table below	8560 at release* 10,130 at 28 days*

* Largest measured values.

Eastbound Class H(HPC)

Date Cast	Girder No.	Release			Design		
		Slump, in	Age, hours	Comp. Strength, psi	Slump, in	Age, days	Comp. Strength, psi
2/19/97	E13, E14	9	19	8620	8-3/4	28	15,120
2/25/97		9	37	10,820	8-1/2	28	14,890
3/3/97		9	19	8710	8	35	14,520
3/8/97	E24, E26	8	46	11,630	8-1/4	28	14,040
3/15/97		8	45	10,420	8-3/4	30	15,240
3/22/97	E33, E34	5	42	11,250	7-3/8	30	14,290
3/29/97	E35	9	42	10,930	9	28	14,450
4/7/97		8	19	8860	3-1/2	28	14,160
4/12/97	E44, E45	8	46	10,240	8	56	13,830
4/18/97		7	22	8270	7	28	14,600
4/28/97		7-1/2	21	10,040	8	29	14,650
4/29/97		8-3/4	17	9520	8-3/4	28	14,270
Average		8		9940	7-3/4		14,510

B. Measured Properties from QC Tests of Production Concrete for Precast Panels

Cement Composition: Not Available
Actual Curing Procedure for Panels: —
Curing Procedure for Cylinders: —

Slump and Compressive Strength:
Eastbound Class H(HPC)

Date Cast	Release			Design		
	Slump, in	Age, hours	Comp. Strength, psi	Slump, in	Age, days	Comp. Strength, psi
8/16/96	8	14	4600	7-3/4	7	9100
8/16/96	—	21	5590	—	7	6620
8/19/96	4-1/2	19	5560	2-1/2	7	6550
8/19/96	4	15-1/2	5080	3-1/2	7	8760
8/20/96	3-1/2	20-1/4	5270	2	7	6750
8/20/96	3-1/2	17	4960	2	7	6520
8/20/96	5	16	4880	—	7	6770
8/20/96	2-1/2	20	5450	2-3/4	7	7010
8/22/96	7	20	5160	4	7	6660
8/22/96	4	17	5560	5	7	6930
8/23/96	4	20	4880	5	7	6620
8/29/96	—	23	4790	—	7	8600
9/4/96	4-1/4	24	4010	—	7	6960
9/10/96	4	20	4570	3-1/2	2	6450

C. Measured Properties from QC Tests of Production Concrete for Cast-in-Place Deck

Cement Composition: Not available
Actual Curing Procedure for Deck: Wet mat curing for 10 days on all eastbound spans and westbound Spans 1-5
Curing Procedure for Cylinders: AASHTO T 23 Initial and Standard Curing

Slump, Concrete Temperature, Air content, and Compressive Strength:
Eastbound Class K(HPC)

Date Cast	Eastbound Span No.	Slump, in	Concrete Temp., °F	Air Content, %	Compressive Strength, psi		
					5 days	7 days	28 days
6/12/97	1	5-1/2	77	7	5181 (4)	5373	6680
		5	78	6.2	6103 (4)	6991	7358
6/25/97	2	7-1/2	80	6.0	4755	5815	—
		8	75	6.2	5986	5657	—
7/9/97	3	8	80	6.2	6216	5792	—
		7	88	6.2	5976	6357	—
7/23/97	4	8	81	6.0	6481	6056	8180
		8	83	6.3	5779	6245	7454
7/26/97	5	7-3/4	84	6.8	5746 (4)	6100	7269
		7-1/2	83	6.4	5991 (4)	6128	—
8/19/97	6	8-1/4	80	6.6	5924 (5)	5972	—
		8-1/2	81	7.2	6386 (5)	5735	—
8/28/97	7	8	78	6.0	6253	6540	—
		8-1/4	82	6.0	5506	5804	—
9/4/97	8	7	80	6.0	4286 (4)	6247	7128
		6-1/4	82	5.2	5418 (4)	6049	—
	Average	7.4	80.8	6.3	5749	6054	7345

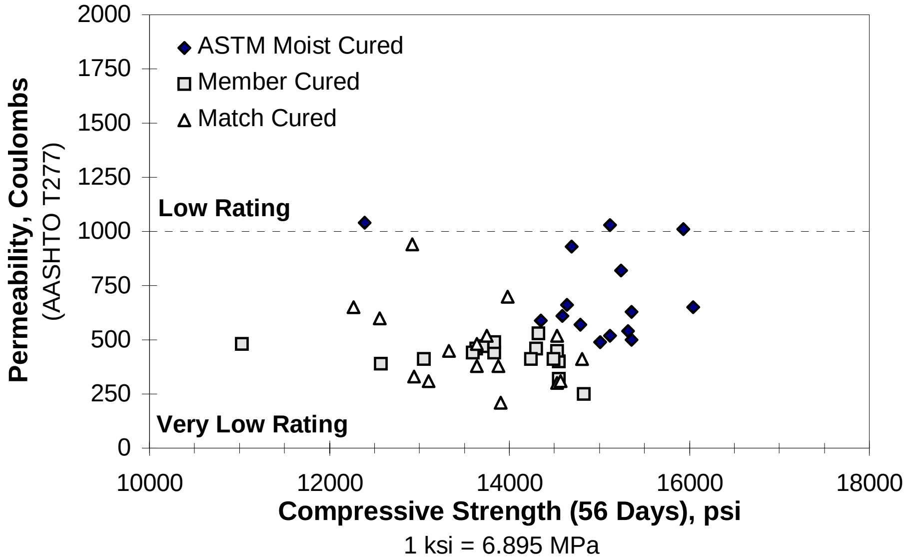
(4) Tested at concrete age of four days.
(5) Tested at concrete age of six days.

Westbound Class S(HPC)
Unit Weight: 145 lb/ft^3
Compressive Strength: 6120 psi at 28 days

D. Measured Properties from Research Tests of Production Concrete for Girders

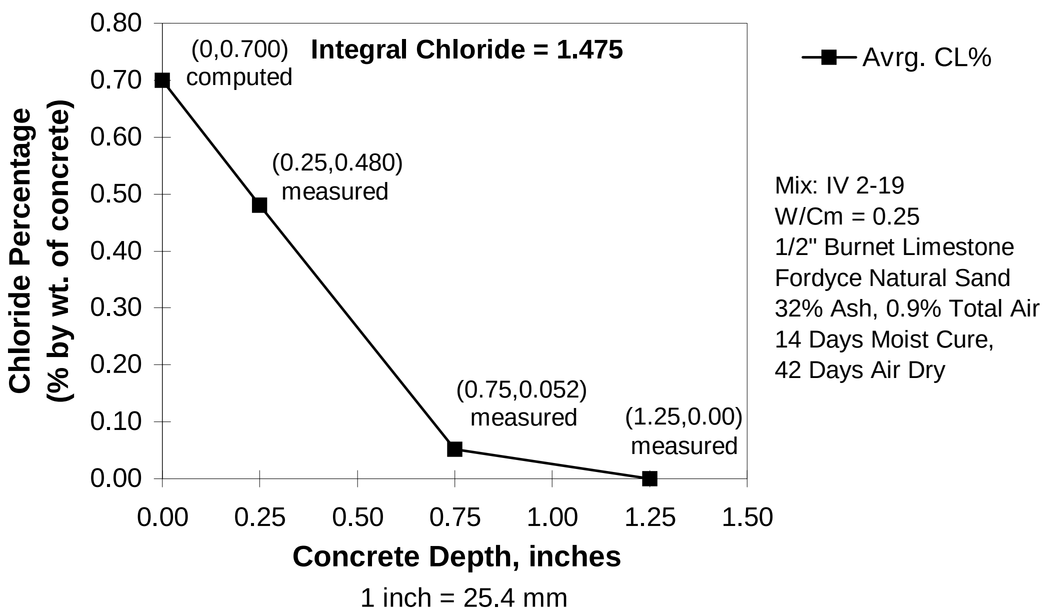
Compressive Strength, Modulus of Elasticity, and Splitting Tensile Strength: See Excel file for girder data

Rapid Chloride Permeability: The following graph contains data from both the San Angelo and Louetta Road bridges



See Excel file for girder data.

Chloride Ion Penetration:
(AASHTO T 259)
Chloride percentages are the average of six samples.



Creep and Shrinkage:

All 4x20-in cylinders stored alongside the beams for 8 to 18 hours, stripped at approximately 24 hours after casting and loaded at age 2 days to 20 and 40 percent of the nominal design compressive strength of the mix. Temperature and humidity were not controlled. Average relative humidity was 55 percent.

Days after Loading	Creep Coefficient (6)		Specific Creep (6), millionths/psi		Shrinkage (7), millionths	
	Eastbound Class H (HPC)	Westbound Class H	Eastbound Class H (HPC)	Westbound Class H	Eastbound Class H (HPC)	Westbound Class H
7	0.73	0.47	0.120	0.079	223	98
28	0.92	0.71	0.151	0.120	307	242
56	1.06	0.75	0.174	0.126	353	269
180	1.25	0.85	0.205	0.42	382	298

(6) Reported creep values are the average values for specimens loaded to the 20 and 40 percent levels. Nine readings were taken on each specimen.
(7) Shrinkage values include adjustments for one day of drying before initial readings were taken and for length changes caused by variation in concrete temperatures.

E. Measured Properties from Research Tests of Production Concrete for Precast Panels

Compressive Strength,
Modulus of Elasticity, and
Coefficient of Thermal Expansion:

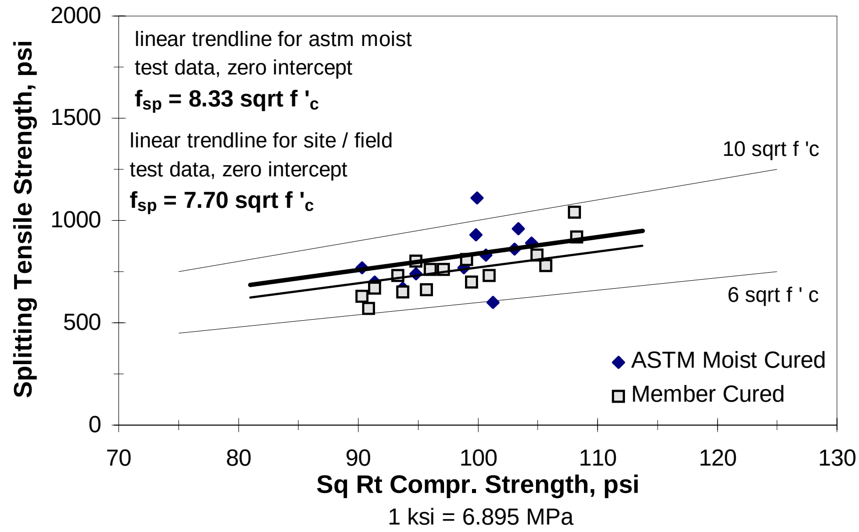
All 4x8-in cylinders cured alongside the panels before and after release and tested using neoprene pads and steel caps.

Bridge	Release Test Age, hours	Compressive Strength (8), psi		Modulus of Elasticity (8), ksi		Coefficient of Thermal Expansion (9), mill/^{o}F
		Release	56 days HPC 28 days non-HPC	Release	56 days HPC 28 days non-HPC	
Eastbound HPC	24	3140	10,100	2990	4620	4.7
Westbound non-HPC	24	5310	8250	3990	4680	4.6

(8) Average values for all instrumented panels cast 2/5/97 for Eastbound and 9/4/96 for Westbound.
(9) Average of two increasing and two decreasing values between 40 and 120 ^{o}F at 60% relative humidity.

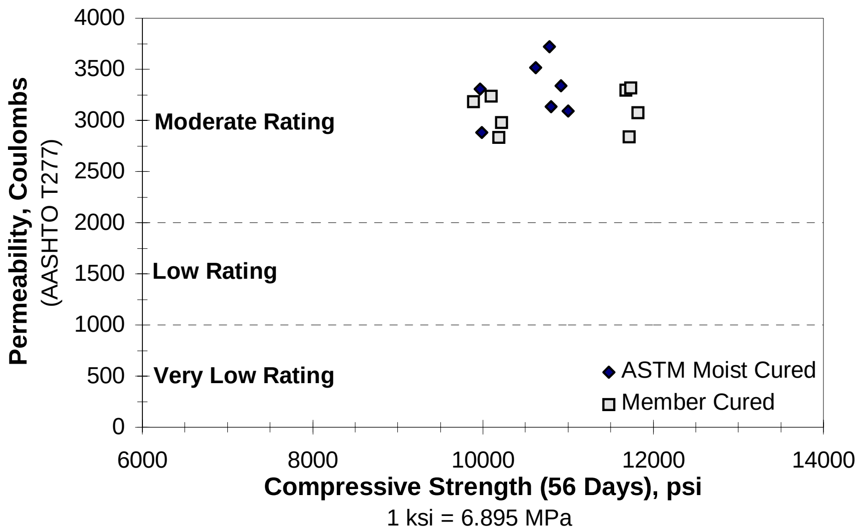
See Excel file for panel data.

Splitting Tensile Strength:



See Excel file for panel data.

Chloride Permeability:



See Excel file for panel data.

Creep and Shrinkage:

All 4x20-in cylinders stored alongside the panels for 8 to 18 hours, stripped at approximately 24 hours after casting and loaded at age 2 days to 20 and 40 percent of the nominal design compressive strength of the mix. Temperature and humidity were not controlled. Average relative humidity was 55 percent.

Days after Loading	Creep Coefficient (10)		Specific Creep (10), millionths/psi		Shrinkage (11), millionths	
	Eastbound Class H (HPC)	Westbound Class H	Eastbound Class H (HPC)	Westbound Class H	Eastbound Class H (HPC)	Westbound Class H
7	0.58	0.74	0.133	0.168	135	249
28	1.12	1.07	0.257	0.244	330	360
56	1.41	1.37	0.324	0.310	404	387
180	1.95	1.97	0.445	0.444	528	428

(10) Reported creep values are the average values for specimens loaded to the 20 and 40 percent levels. Nine readings were taken on each specimen.
(11) Shrinkage values included adjustments for one day of drying before initial readings were taken and for length changes caused by variation in concrete temperatures.

F. Measured Properties from Research Tests of Production Concrete for Cast-in-Place Deck

Compressive Strength,
Modulus of Elasticity, and
Coefficient of Thermal Expansion:

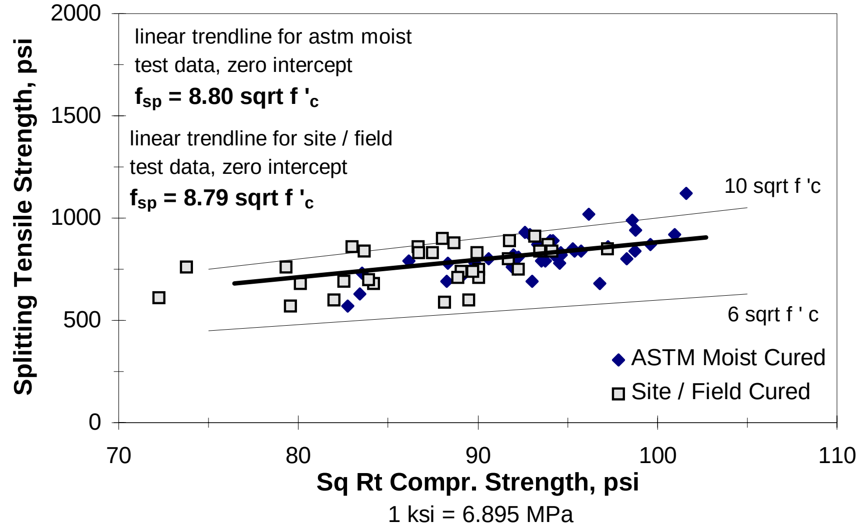
All 4x8-in cylinders cured alongside the deck.

Span	Compressive Strength (12), psi	Modulus of Elasticity, ksi	Coefficient of Thermal Expansion (13), mill/^{o}F
Eastbound HPC—Class K (HPC)			
1	7290	5500	4.6
2	8420	5230	
3	9060	6060	
4	7550	5790	
5	8220	5010	
6	8680	5380	
7	7460	4920	
8	7770	5570	
Westbound Class S (HPC)			
1	6400	5170	4.4
2	5160	4670	
3	4450	4310	
4	4700	4670	
5	4560	4640	
Westbound Class S			
6 and 7	5340	4930	4.9

(12) At 56 days for HPC mixes. At 28 days for non-HPC mixes.
(13) Average of two increasing and two decreasing values between 40 and 120 ^{o}F at 60% relative humidity.

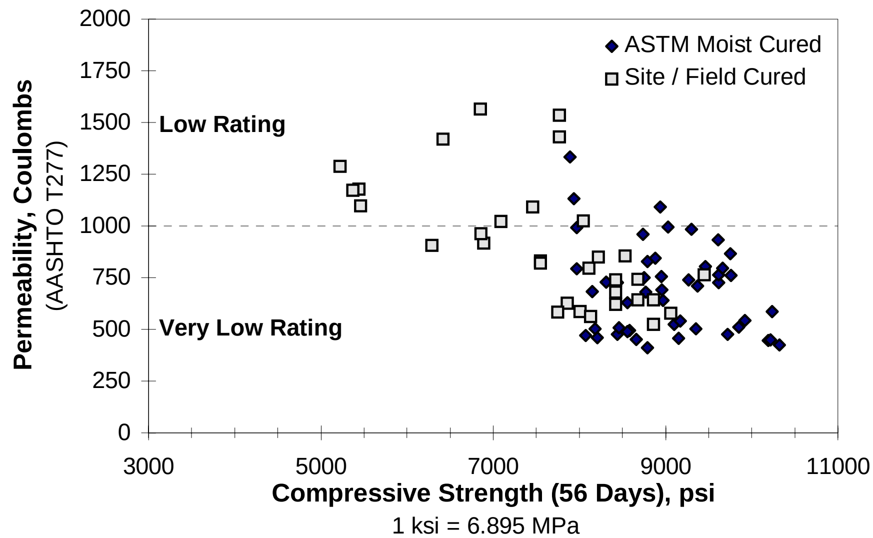
See Excel file for deck data.

Splitting Tensile Strength:
Class K(HPC)



See Excel file for deck data.

Chloride Permeability:
Class K(HPC)



See Excel file for deck data.

Chloride Ion Penetration:
(AASHTO T 259)

Concrete Class	K (HPC)	K (HPC)	S	S (HPC)
Casting Date	6/12/97	8/19/97	2/15/97	12/3/96
Depth, in				
0.25	0.201	0.156	0.368	0.269
0.75	0.000	0.000	0.058	0.000
1.25	0.000	0.000	0.000	0.000
Integral Chloride	0.56	0.44	1.17	0.85

Values are chloride percentage by weight of concrete.
Specimens moist cured for 14 days followed by 42 days drying and ponding for 90 days.

Freeze-Thaw Resistance:
(ASTM C 666)

Concrete Class	Casting Date	Total Cycles	Mass Change, percent	Durability Factor
K (HPC) (14)	6/12/97	300	-0.86	97.9
		300	-1.12	99.0
		300	-0.92	96.9
K (HPC) (15)	6/12/97	300	-1.15	97.0
		300	-1.06	98.0
		300	-1.30	98.0
K (HPC) (14)	6/25/97	300	-0.35	97.1
		300	-0.28	97.1
		300	-0.32	96.0
K (HPC) (14)	7/9/97	300	-0.76	97.0
		300	-1.17	98.0
		300	-0.96	97.0
K (HPC) (15)	7/9/97	300	-0.92	96.9
		300	-0.65	96.9
		300	-0.85	97.5
K (HPC) (14)	7/23/97	300	-0.40	99.9
		300	-0.64	97.0
		300	-0.72	98.4
K (HPC) (15)	7/23/97	300	-0.34	101.1
		300	-0.46	99.0
		300	-0.43	100.0
K (HPC)	Average	—	-0.75	97.9
S (14)	2/15/97	314	-1.88	95.7
		314	-2.36	99.0
		314	-2.22	94.0
S (14)	2/18/97	300	-3.64	91.4
		300	-3.20	89.4
		300	-3.21	92.1
S (14)	2/28/97	300	-2.16	96.7
		300	-2.04	93.7
		300	-2.28	96.9
		300	-1.54	98.9
		300	-1.62	96.8
		300	-3.35	96.8
S (14)	Average	—	-2.46	95.1

(14) Concrete samples obtained from ready-mix truck.
(15) Concrete samples obtained from concrete pump.

Concrete Class	Casting Date	Total Cycles	Mass Change, percent	Durability Factor
S (HPC) (14)	1/29/97	302	-2.93	98.6
		302	-2.79	99.0
		302	-3.70	99.0
S (HPC) (14)	3/4/97	300	-2.28	94.5
		300	-1.69	97.1
		300	-1.59	96.9
		300	-1.65	96.9
		300	-1.58	96.9
		300	-1.52	96.9
S (14)	Average	—	-2.19	97.3

(14) Concrete samples obtained from ready-mix truck.
(15) Concrete samples obtained from concrete pump.

Abrasion Resistance:
(ASTM C 944)

Concrete Class	Casting Date	Depth of Wear (16), in	Percent Wear
K (HPC) (17)	6/12/97	0.025	7.3
		0.039	12.5
		0.058	17.8
K (HPC) (18)	6/25/97	0.039	11.3
		0.024	7.2
		0.039	8.7
K (HPC) (18)	7/9/97	0.035	11.7
		0.040	14.5
		0.063	23.8
K (HPC) (17)	7/9/97	0.043	11.0
		0.033	12.9
		0.049	14.9
K (HPC) (18)	7/23/97	0.036	10.7
		0.034	9.8
		0.038	11.2
K (HPC)	Average (17)	0.041	12.7
	Average (18)	0.039	12.1
S (18)	2/18/97	0.041	9.9
		0.041	10.4
S (18)	2/28/97	0.058	13.5
		0.046	13.1
		0.048	18.1
S	Average	0.047	13.0
S (HPC) (18)	3/4/97	0.077	20.4
		0.097	25.0
		0.043	11.1
S (HPC)	Average	0.072	18.8

(16) Measurements made after 6 minutes of testing.
(17) Concrete sample obtained from concrete pumps.
(18) Concrete sample obtained from ready-mix truck.

Scaling Resistance:
(ASTM C 672)

Concrete Class	Casting Date	Conditioning Rating
K (HPC) (19)	6/12/97	3
		3
K (HPC) (20)	6/25/97	4
		4
K (HPC) (20)	7/9/97	3
		3
K (HPC) (19)	7/9/97	1
		1
K (HPC) (20)	7/23/97	1
		2
K (HPC)	Average (20)	3
	Average (19)	2
S (20)	2/18/97	4
		3.5
S (20)	2/28/97	5
		5
S (20)	Average	4.5
S (HPC) (20)	3/4/97	0
		0
S (HPC) (20)	Average	0

(19) Concrete sample obtained from concrete pumps.
(20) Concrete sample obtained from ready-mix truck.

Creep and Shrinkage:

All 4x20-in cylinders stored alongside the cast-in place deck for 8 to 18 hours, stripped at approximately 24 hours after casting and stored in the testing room until loaded at age 28 days to 20 and 40 percent of the nominal design compressive strength of the mix. Temperature and humidity were not controlled. Average relative humidity was 55 percent.

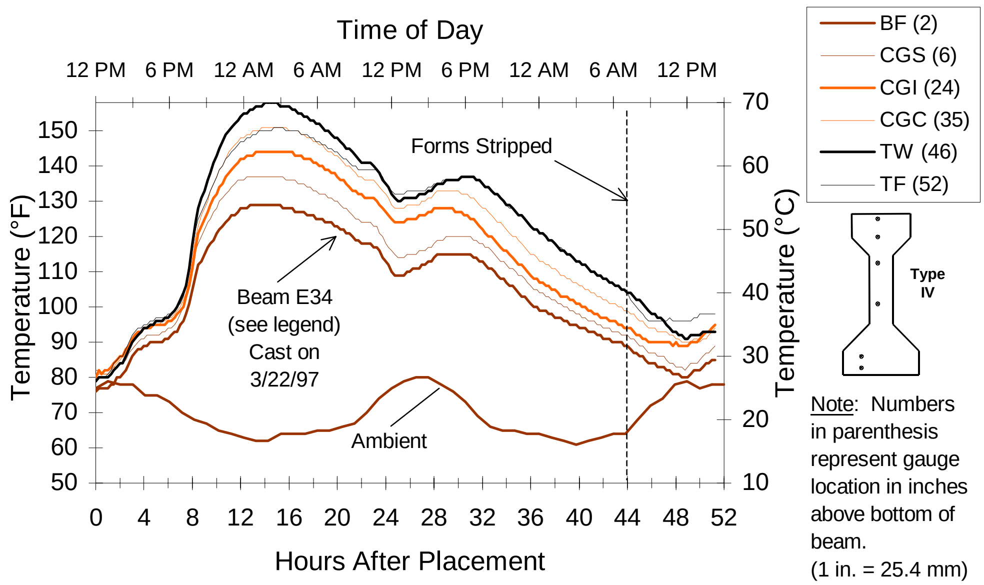
Days after Loading	Creep Coefficient (21)			Specific Creep (21), millionths/psi			Shrinkage (22), millionths		
	Eastbound	Westbound		Eastbound	Westbound		Eastbound	Westbound	
	Class K (HPC)	Class S (HPC)	Class S	Class K (HPC)	Class S (HPC)	Class S	Class K (HPC)	Class S (HPC)	Class S
7	0.72	0.65	0.53	0.108	0.212	0.106	138	125	118
28	1.07	1.21	0.94	0.161	0.390	0.186	251	269	258
56	1.25	1.51	1.43	0.188	0.488	0.284	285	371	340
180	1.59	2.23	1.96	0.240	0.722	0.389	265	462	434

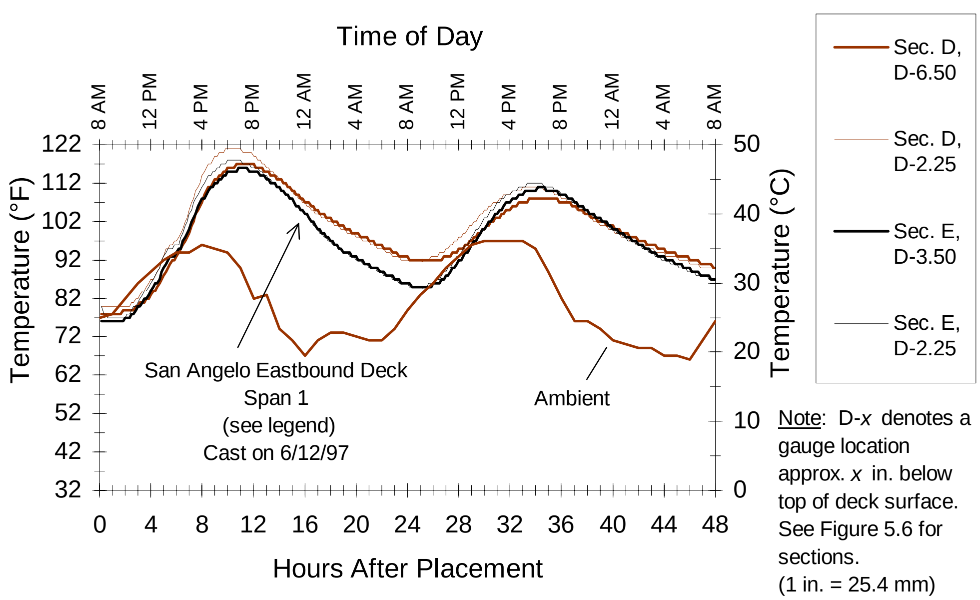
(21) Reported creep values are the average values for specimens loaded to the 20 and 40 percent levels. Nine readings were taken on each specimen.
(22) Shrinkage values included adjustments for one day of drying before initial readings were taken and for length changes caused by variation in concrete temperatures.

7. OTHER RESEARCH DATA

A significant amount of research was conducted in connection with the construction of the San Angelo bridge. Data were collected on concrete curing temperatures, thermal gradients, and temperatures in the bridge; concrete strains, prestress losses, camber, and deflection; and responses during static live load tests. The following sections report key data. For more detailed results, consult the project final reports.

Concrete Curing Temperatures:





Member	Concrete Temperature, ^oF			
	Placement (23)	Peak (24)	Max. Rise (24,25)	Max. Gradient (26)
Eastbound HPC Beams				
E13	83	141	54	19
E14	83	144	54	21
E24	81	139	55	20
E26	83	139	54	26
E33	83	157	59	27
E34	79	158	60	29
E35	87	150	56	28
Westbound Non-HPC Beams				
W 17 (27)	80	155	66	26
Eastbound HPC Panels				
SHP11	67	68	2	2
SHP21	70	71	3	1
SHP22	67	67	2	1
SHP31	69	72	4	1
SHP41	67	71	3	1
Westbound Non-HPC Panels				
SNP1	93	106	6	5
SNP2	93	105	5	4
Eastbound Deck				
SE1-D	79	121	34	7
SE1-E	78	118	31	4
SE2-D	78	108	25	6
SE2-E	76	101	20	1
SE3-D	85	121	28	17

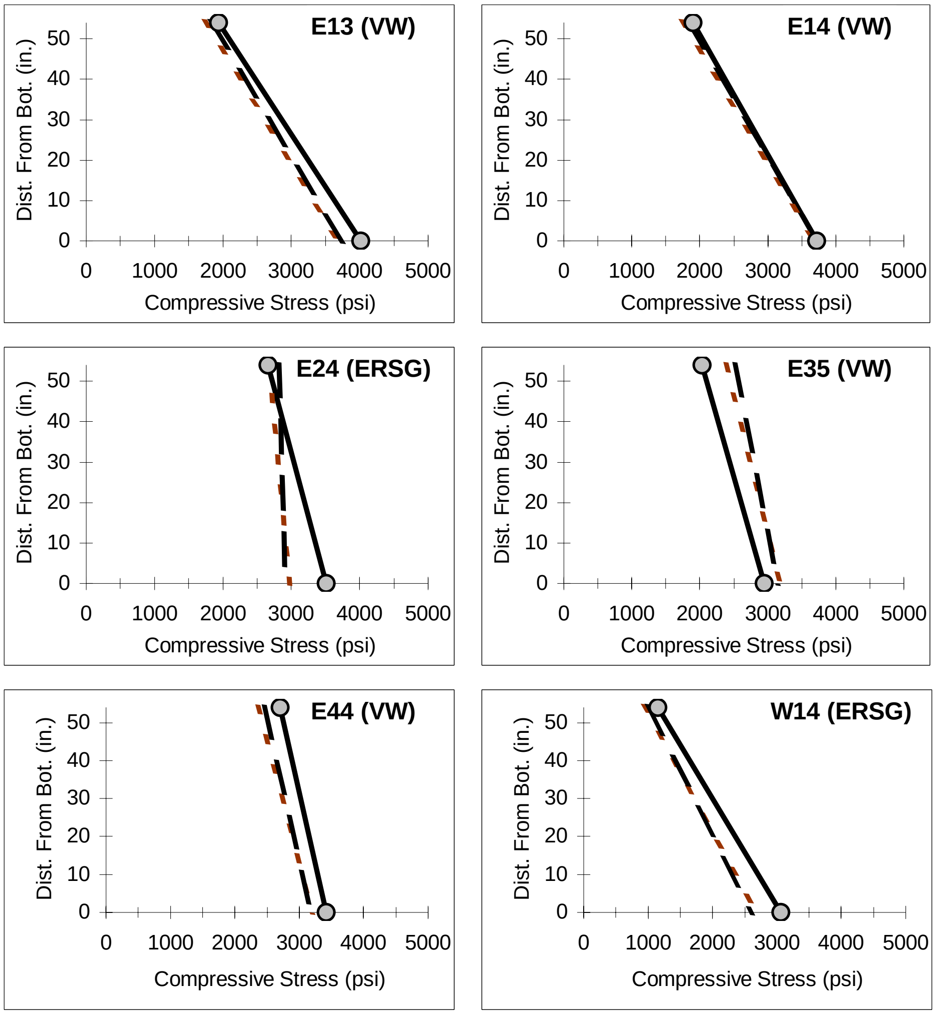
(23) Average temperature for all gages in a beam, and average of two locations in panels and decks.
(24) At a single gage location usually located at the centroid of the top flange.
(25) The temperature rise in the HPC beams is equivalent to 8.0 to 8.9 ^oF per 100 lb/yd^3 of cement or 5.5 to 6.1 ^oF per 100 lb/yd^3 of cementitious material.
(26) Between two gage locations.
(27) Steam cured to maintain a favorable temperature under the tarpaulin.

Thermal Gradients:

	Westbound (28)	Eastbound (29)
Measured Thermal Gradient (30), ^{o}F		
Positive Gradient	36	28
Negative Gradient	13	12
Highest Average Measured Gradient for a Calendar Month, ^{o}F		
Positive Gradient	28 (31)	21 (32)
Negative Gradient	8 (33)	7 (33)

(28) Data collected for the full 1997 calendar year.
(29) Data collected for nine months beginning July 1997.
(30) Temperature difference between the beam and the location of the top deck gage. This ranged from 2.00 to 2.25 in below the deck surface.
(31) Average for June 1997.
(32) Average for March 1998.
(33) Average occurred in many months.

Concrete Stresses at
Release of Pretensioning:

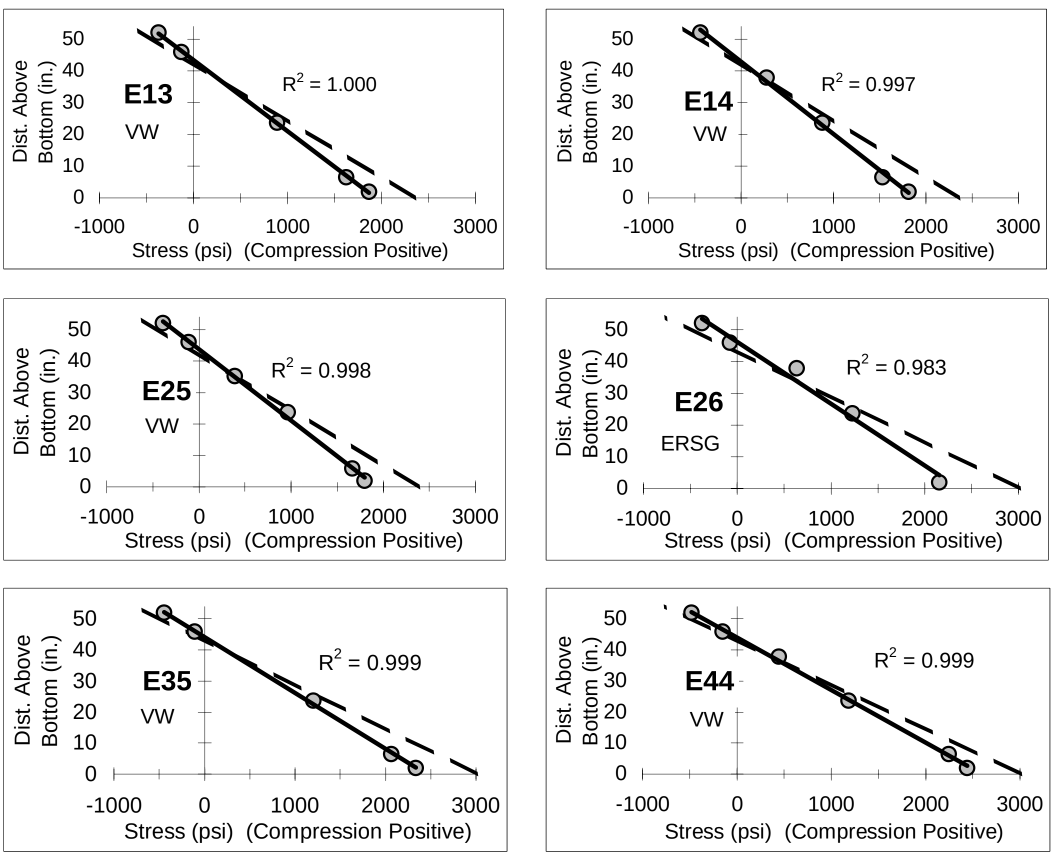


Note: Solid lines represent "measured" stresses determined by multiplying measured strains by modulus of elasticity from tests on companion specimens. Dotted lines represent "design" prediction. Dashed lines represent "measured" prediction. (See Table 6.2 for assumptions.)

Table 6.2 follows.

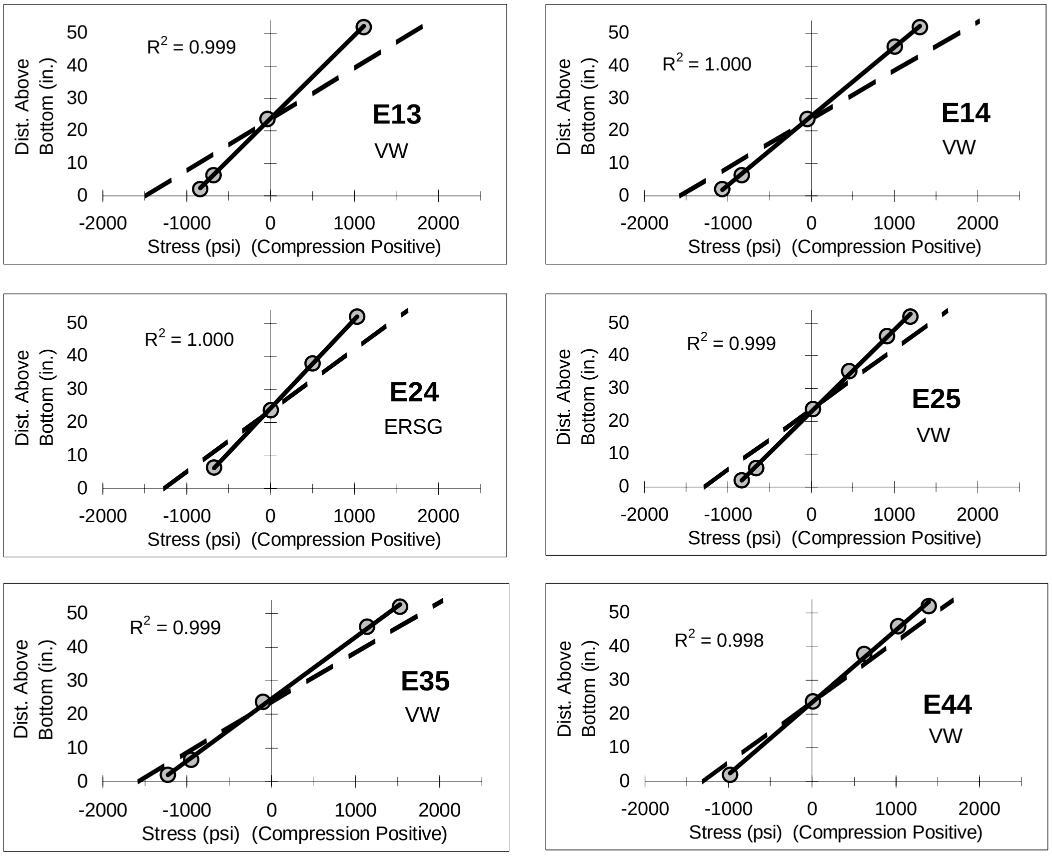
Parameters	Design Analysis	Measured Analysis
Sectional Properties	Gross section	Transformed section
Prestress Force/Loss	No loss assumed before release. Elastic shortening loss calculated by approximate method given in *AASHTO LRFD Specifications*	3.5 to 4.5 % loss assumed before release
Beam Self-Weight	Gross beam area at 150 lb/ft^3 (3.29 kg/m^3)	Gross beam area and measured unit weight, with approx. weight of steel included.
Modulus of Elasticity	$33w^{1.5}\sqrt{f'_c}$ for Westbound $40{,}000\sqrt{f'_c} + 1{,}000{,}000$ for Eastbound	Based on tests of companion specimens

Concrete Stresses from Post-Tensioning:



Note: Points represent measured stresses (strains multiplied by measured modulus of elasticity). Solid lines represent regression lines fit to measured data (coefficient of determination given on each chart). Dashed lines represent predicted stresses based on analysis using measured modulus of elasticity and net transformed section properties.

Concrete Stresses from Placement of
Cast-in-Place Deck:



Note: Points represent measured stresses (strains multiplied by measured modulus of elasticity). Solid lines represent regression lines fit to measured data (coefficient of determination given on each chart). Dashed lines represent predicted stresses based on analysis using measured modulus of elasticity, measured deck thickness, and transformed section properties.

Prestress Losses:

Beam	Days after Release	Loss Components, ksi					
		PR (34)	ES at Release	ES (35)	CR + SH (36)	RE	TOTAL
Eastbound Beams Class H (HPC)							
E13	422	8.10	17.72	25.03	15.02	2.46	50.61
E14	422	8.10	16.66	24.58	22.10	2.46	57.24
E24	404	9.11	14.92	20.19	19.78	2.43	51.51
E25	746	8.10	14.59	22.46	18.63	2.77	51.95
E34	316	9.11	21.64	30.86	15.17	2.30	57.43
E35	309	9.11	21.25	30.52	16.26	2.28	58.17
E44	305	9.11	16.27	26.15	18.09	2.28	55.63
Westbound Beams Class H							
W14	771	7.09	13.94	13.94	10.84	2.79	34.67
W15	771	7.09	14.73	14.73	9.81	2.79	34.41
W16	771	7.09	12.18	12.18	10.62	2.79	32.68
W17	776	7.09	12.80	12.80	7.84	2.79	30.51

ES = Elastic shortening component measured using a combination of vibrating wire strain gages and electrical resistance strain gages.
CR+SH = Creep and shrinkage component determined as the difference between total shortening and elastic shortening measured with vibrating wire strain gages.
RE = Relaxation component after release calculated for low relaxation strand.
(34) PR = Pre-release component calculated as 4.5, 4.0, or 3.5 percent of the nominal jacking stress.
(35) Includes elastic loss in pretensioned reinforcement caused by post tensioning.
(36) Includes compensation for measured elastic change in stress from superimposed dead load.

Camber and Deflection:

All camber and deflection values in inches. Negative values indicate downward deflection.

Beam No.	Camber at Release		Camber Growth (37)		Post Tension-ing (40)	CIP Deck (41)	Total Deck (42)	Long Term (38)	
	Actual	Corrected (39)	Days of Data	Camber				Days of Data	Camber
E13	1.52	1.49	25	0.87	1.42	-1.23	—	424	2.09
E14	1.55	1.52	25	0.86	1.40	-1.58	—	424	2.42
E24	0.61	0.10	17	0.59	2.59	-1.88	-4.18	406	2.08
E25	0.23	-0.26	24	0.34	2.15	-2.14	-4.31	748	1.45
E26	0.80	0.29	17	0.54	2.47	-2.91	-4.56	406	0.84
E33	0.87	0.36	28	0.81	2.42	-1.93	-4.43	392	1.77
E34	0.76	0.34	28	0.70	2.36	-2.05	-4.53	392	1.27
E35	1.15	0.98	31	1.04	2.29	-2.79	-4.43	385	2.35
E44	0.94	0.52	24	1.15	2.36	—	—	371	2.33
E45	0.89	0.47	24	0.99	2.66	—	—	371	1.71
W14	1.13	0.98	119	0.55	—	-1.05	-2.21	773	-1.43
W15	1.01	0.83	119	0.90	—	-0.90	-2.05	773	-1.55
W16	0.79	0.53	119	0.90	—	-1.03	-2.15	773	-1.51
W17	1.09	0.68	114	0.83	—	-1.37	-2.33	768	-2.13

(37) Growth in camber during storage at the plant.
(38) Total measured long-term camber.
(39) Actual values corrected for thermal gradient in the beam. All other data are also corrected.
(40) Deflection caused by post-tensioning.
(41) Deflection caused by placing the cast-in-place deck.
(42) Deflection taken as the difference between readings before placement of precast panels and after placement of the cast-in-place deck.

Live Load Tests
Loadings:

SW-A	One truck pair centered over Beam W16 near midspan of WB Span 1. For general comparison with Loadings SE-A1 and SE-A2
SE-A1 SE-A2	One truck pair centered over Beam E13 near midspan of EB Span 1. Loading repeated twice at different times during test.
SE-B	Two truck pairs placed near midspan of EB Span 1. Outer edge of wheel lines for each truck pair at 2.0 ft from centerline of Beam E 13. Intended to produce approximately maximum stress in Beam E 13.
SE-C	One truck pair centered over Beam E25 near midspan of EB Span 2.
SE-D	One truck pair centered over Beam E34 near midspan of EB Span 3.
SE-E	Loading SE-C and SE-D applied simultaneously. For investigation of possible continuity across Bent 3.

Test Results:

Beam (43)	Measured Deflection (44), in	Measured Curvature (45), millionths/in	Moment Computed	
			Deflection (46), ft-kip	Curvature (47), ft-kip
Loading SW-A				
W11	-0.01	—	17	—
W12	-0.03	—	48	—
W13	-0.08	—	127	—
W14	-0.15	—	238	—
W15	-0.23	—	336	—
W16	-0.30	1.07	484	403
W17	-0.33	1.16	546	448
Loading SE-A1				
E11	-0.07	—	147	—
E12	-0.17	—	384	—
E13	-0.31	1.34	701	706
E14	-0.27	1.11	567	544
Loading SE-A2				
E11	-0.08	—	168	—
E12	-0.18	—	407	—
E13	-0.33	1.50	746	788
E14	-0.30	1.18	630	579
Loading SE-B				
E11	-0.21	—	442	—
E12	-0.44	—	997	—
E13	-0.58	2.71	1314	1428
E14	-0.58	2.45	1220	1201

(43) W = Westbound. E = Eastbound. First number is the span. Second number is the beam line
(44) Midspan deflection measured using precise surveying. Negative values indicate downward deflection.
(45) Midspan curvature determined by fitting a regression line through the measured concrete strains at several depths. Positive values indicate a downward deflection.
(46) Midspan moments computed using composite section properties based on measured moduli of elasticity for beam and deck concrete, measured deck thickness, and effective flange width per Article 8.10.1 of the *AASHTO Standard Specifications*. Moment diagram based on measured truck loads was used to establish the relationship between midspan deflection and midspan moment.
(47) Midspan moment calculated from midspan curvature using composite section properties.

Beam (43)	Measured Deflection (44), in	Measured Curvature (45), millionths/in	Moment Computed	
			Deflection (46), ft-kip	Curvature (47), ft-kip
Loading SE-C				
E21	-0.13	—	203	—
E22	-0.33	—	483	—
E23	-0.42	—	615	—
E24	-0.52	—	762	—
E25	-0.59	1.27	861	602
E26	-0.65	—	1014	—
Loading SE-D				
E31	-0.08	—	106	—
E32	-0.22	—	345	—
E33	-0.35	—	548	—
E34	-0.37	—	580	—
E35	-0.40	1.16	532	458
Loading SE-E				
E21	-0.11	—	172	—
E22	-0.29	—	425	—
E23	-0.38	—	557	—
E24	-0.48	—	703	—
E25	-0.51	1.42	745	671
E26	-0.61	—	952	—
E31	-0.13	—	173	—
E32	-0.19	—	298	—
E33	-0.31	—	486	—
E34	-0.43	—	674	—
E35	-0.47	1.07	626	421

(43) W = Westbound. E = Eastbound. First number is the span. Second number is the beam line
(44) Midspan deflection measured using precise surveying. Negative values indicate downward deflection.
(45) Midspan curvature determined by fitting a regression line through the measured concrete strains at several depths. Positive values indicate a downward deflection.
(46) Midspan moments computed using composite section properties based on measured moduli of elasticity for beam and deck concrete, measured deck thickness, and effective flange width per Article 8.10.1 of the *AASHTO Standard Specifications*. Moment diagram based on measured truck loads was used to establish the relationship between midspan deflection and midspan moment.
(47) Midspan moment calculated from midspan curvature using composite section properties.

8. OTHER RELATED RESEARCH

Transfer and Development Lengths

Prior to construction of the San Angelo Bridge, tests were made to determine the transfer and development lengths for 0.6-in-diameter strands in HPC with a strand spacing of 2 in. Two rectangular beams known as Hoblitzell-Buckner Beams and Texas Type C beams were tested.

Hoblitzell-Bucker Beams
Transfer Length: 13 to 17 in
Development Length:

Test (48)	Embedment Length, in	Concrete Compressive Strength, psi	Failure Type (49)
1	163	13,100	Flexural
2	119	13,100	Flexural
3	102	13,200	Flexural
4	78	13,200	Flexural

(48) Beams were 14x42 in and contained six 0.6-in-diameter strands at 2-in centers. Concrete compressive strength at release was 7700 psi.
(49) Since all test specimens failed in flexure, the development length was less than 78 in.

Texas Type C Beams
Transfer Length: 18 to 24 in
Development Length:

Test (50)	Embedment Length, in	Concrete Compressive Strength, psi	Failure Type (51)
1	120		Flexural
2	93		Flexural
3	78		Flexural
4	72		Flexural

(50) Beams were 40-in deep with a 72-in-wide by 7-1/2-in-deep concrete deck and contained sixteen 0.6-in-diameter strands at 2-in centers.
(51) Since all test specimens failed in flexure, the development length was less than 72 in.

9. SOURCES OF DATA

Myers J. J. and Carrasquillo, R. L., "Production and Quality Control of High Performance Concrete in Texas Bridge Structures," Center for Transportation Research, The University of Texas at Austin, Research Report No. 580/589-1, 2000, 553 pp. To be published.

Gross, S. P. and Burns, N. H., "Field Performance of Prestressed High performance Concrete Highway Bridges in Texas," Center for Transportation Research, The University of Texas at Austin, Research Report No. 580/589-2, 2000, 656 pp. To be published.

Ralls, M. L., "Texas HPC Bridge Decks," *Concrete International*, Vol. 21, No. 2, February 1999, pp. 63-65.

Ralls, M. L., "Texas High Performance Concrete Bridges—How Much Do They Cost?" *Concrete International*, Vol. 20 No. 3, March 1998, pp. 71-74.

Ralls, M. L. and Carrasquillo, R. L., "Texas High Performance Concrete Bridges—Implementation Status," *Symposium Proceedings, PCI/FHWA International Symposium on High Performance Concrete*, New Orleans, LA, Precast/Prestressed Concrete Institute, Chicago, IL, 1997, pp. 691-704.

SHRP High Performance Concrete Bridge Showcase Notebook, Houston, TX, March 25-27, 1996.

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10. DRAWINGS

Beam Span Lengths, Beam Spacings, and Specified Compressive Strengths

Span No.	Beam Type	Span Length (52), ft	No. of Beams	Beam Spacing, ft	Specified Compressive Strength, psi				
					Original		Modified		
					Release	56 days (53)	Release	Post-tensioning	56 days (53)
Eastbound									
1	IV	131.0	4	11.0	10,800	13,600	8100	9950	13,000
2	IV	157.0	6	6.6	9200	13,500 (54)	8000	9800	14,000
3	IV	150.0	5	8.3	10,300	14,700	8000	10,400	13,800
4	IV	149.0 (55)	5	8.3 (55)	9800	14,000	8000	10,400	13,700
5	IV	140.3 (55)	5	8.5 (55)	8900	10,900	8000	9800	12,500
6	IV	88.9 (55)	5	9.5 (55)	4000	5800			
7	IV	69.8 (55)	7	7.5 (55)	6000 (54)	7600 (54)			
8	B	63.8 (55)	10	6.2 (55)	6800 (54)	7800 (54)			
Westbound									
1	IV	131.0	7	5.7	5770	7850	N/A	N/A	N/A
2	IV	129.0	6	6.9	5940	7910	N/A	N/A	N/A
3	IV	129.0	6	7.3	6160	8150	N/A	N/A	N/A
4	IV	129.0	6	7.8	6560	8540	N/A	N/A	N/A
5	IV	100.0	6	8.3	4020	5000	N/A	N/A	N/A
6	IV	140.3	9	5.4	6210	8920	N/A	N/A	N/A
7	B		5		4000	5000	N/A	N/A	N/A
8	IV				5940	7910	N/A	N/A	N/A
9	IV		7		6200 (54)	8790 (54)	N/A	N/A	N/A

(52) Between centerline of bents.
(53) 56 days for HPC mixes, 28 days for non-HPC mixes.
(54) Maximum value for the span. Other beams have a lower specified strength.
(55) Individual values within the span vary. Average values reported.

Lateral Stability Considerations

As stated on the bridge drawings:

Lateral stability of the beams during lifting from the bed, during shipment, and during placement shall be investigated by the fabricator.

- An increase in the beams required initial release strength may be necessary to allow lifting loops to be moved in from the beam ends.
- The use of double (side-by-side) lifting loops is encourage in order to minimize initial lifting eccentricity.
- Beam sweep shall be kept to a minimum.
- A rigid yoke lifting assembly may be required for lifting operations.

11. HPC SPECIFICATIONS

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*F.R. DIV.6 * TEXAS       STP 95(208)UM     ETC * SHEET
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  TOM GREEN     COUNTY * HWY US 67       *CONT   77-6-67,ETC
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HIGH PERFORMANCE CONCRETE (HPC)

ITEMS 420, 421, 422, 424 AND 440

THE DESIGN AND CONSTRUCTION OF A PORTION OF THIS PROJECT, THE NORTH CONCHO RIVER, U.S. 87 & S.O. RR OVERPASS EASTBOUND MAINLANES, IS PART OF A FEDERAL DEMONSTRATION RESEARCH PROJECT ON THE USE OF HIGH PERFORMANCE CONCRETE (HPC) IN BRIDGE STRUCTURES. THIS STUDY IS CO-SPONSORED BY THE FEDERAL HIGHWAY ADMINISTRATION (FHWA) AND THE TEXAS DEPARTMENT OF TRANSPORTATION (TXDOT). THE INVESTIGATING TEAM (RESEARCHERS) IS WITH THE CENTER FOR TRANSPORTATION RESEARCH OF THE UNIVERSITY OF TEXAS AT AUSTIN. THE SUCCESS OF BOTH THE CONSTRUCTION PROJECT AND THE RESEARCH REQUIRES THAT THE RESEARCHERS PLAY AN INTEGRAL PART IN THE CONSTRUCTION PROCESS, AND THAT THE CONTRACTOR AND SUBCONTRACTORS COOPERATE FULLY WITH THE RESEARCHERS. THE FOLLOWING SECTION DESCRIBES SPECIAL CONSIDERATIONS REQUIRED OF THE CONTRACTOR, AND OUTLINES THE ROLE OF THE RESEARCHERS IN VARIOUS ASPECTS OF THE CONSTRUCTION PROCESS.

THE CONTRACTOR IS GIVEN THE OPTION OF CONSTRUCTING PRECAST SUB-STRUCTURES (CAPS AND COLUMNS), OF THE SAME STRENGTHS AND DIMENSIONS AS THE CAST-IN-PLACE SUBSTRUCTURES, FOR THE NORTH CONCHO RIVER, US 87 & S. 0. OVERPASS. FABRICATION SHALL BE IN ACCORDANCE WITH ITEM 424. THE CONTRACTOR SHALL SUBMIT TO THE STATE COMPLETE DETAILS, INFORMATION AND ALL APPLICABLE DRAWINGS OF THE PROPOSED METHOD, MATERIALS, EQUIPMENT AND PROCEDURES. THESE SHALL BE SUBMITTED SUFFICIENTLY IN ADVANCE OF THE START OF CONSTRUCTION OPERATIONS, TO ALLOW THE STATE NOT LESS THAN

SPECIFICATION DATA

SHEET H

GENERAL NOTES AND SPECIFICATION DATA –

HIGH PERFORMANCE CONCRETE (HPC) CONT'D

14 CALENDAR DAYS FOR REVIEW AND APPROVAL.

COORDINATION OF WORK WITH THE CONTRACTOR

ALL ASPECTS OF THE RESEARCHERS' WORK SHALL BE COORDINATED WITH THE CONTRACTOR. THE CONTRACTOR SHALL TAKE ALL ACTIONS NECESSARY TO INCORPORATE THE RESEARCH ACTIVITIES INTO THE DEVELOPMENT OF THE CONSTRUCTION SCHEDULE.

ATTENDANCE AT A PRE-BID MEETING, WHERE THE RESEARCHERS AND TXDOT PERSONNEL WILL GIVE PRESENTATIONS ON DETAILS CONCERNING THE HIGH STRENGTH CONCRETE (HPC) BRIDGE, IS MANDATORY FOR ALL CONTRACTORS BIDDING ON THIS CONTRACT. AFTER LETTING, A PARTNERING WORKSHOP IS RECOMMENDED AND A PRECONSTRUCTION MEETING WILL BE SCHEDULED WITH THE CONTRACTOR, PERTINENT SUBCONTRACTORS, RESEARCHERS AND SPONSORS.

AT ALL TIMES, INCLUDING DURING CONSTRUCTION, COORDINATION BETWEEN THE CONTRACTOR'S AND RESEARCHERS' AREA REPRESENTATIVES WILL BE REQUIRED TO ENSURE IMPLEMENTATION OF THE NECESSARY MEASURES FOR DESIGN AND CONTROL OF HPC. THE RESEARCHERS WILL BE PROVIDED ACCESS TO THE WORK AREA, AND WILL INSTALL THE INSTRUMENTATION. ANY NECESSARY FACILITIES FOR INSTALLING AND PROTECTING INSTRUMENTATION AND EQUIPMENT WILL BE PROVIDED BY THE CONTRACTOR.

DEFINITION OF HIGH PERFORMANCE CONCRETE (HPC)

FOR THIS CONTRACT, "HIGH PERFORMANCE CONCRETE" SHALL BE DEFINED AS THE CONCRETE IN THE DECK, BEAMS, CAPS AND COLUMNS OF THE EASTBOUND MAIN-LANES OF THE NORTH CONCHO RIVER, U.S. 87 & S.O. RR OVERPASS, THE DECK ONLY OF THE WESTBOUND MAINLANES OF THIS OVERPASS, AND THE BEAMS OF ENTRANCE RAMP E. HIGH PERFORMANCE CONCRETE BEAMS AND PRECAST CONCRETE PANELS ARE CLASS H (HPC) CONCRETE. HIGH PERFORMANCE CONCRETE CAST-IN-PLACE DECK, CAPS, AND COLUMNS OF THE EASTBOUND MAINLANES ARE CLASS K (HPC) CONCRETE AS DEFINED IN THE SPECIAL PROVISIONS TO ITEM 421. THE HIGH PERFORMANCE CONCRETE CAST-IN-PLACE DECK IN THE WESTBOUND MAINLANES IS CLASS S (HPC) CONCRETE.

HIGH PERFORMANCE CONCRETE (HPC) MIX DEVELOPMENT

THE RESEARCHERS WILL PROVIDE TECHNICAL EXPERTISE TO THE CONTRACTOR IN DEVELOPING AND EVALUATING THE HPC MIX DESIGNS. THE DESIGN AND CONTROL OF THE HPC WILL BE IN ACCORDANCE WITH THE STANDARD SPECIFICATIONS, SPECIAL PROVISIONS AND CONTRACT PLANS. EMPHASIS WILL BE GIVEN TO USING THE LOCAL MATERIALS AVAILABLE AS PROPOSED BY THE CONTRACTOR. HOWEVER, HIGHER QUALITY MATERIALS THAN ARE AVAILABLE LOCALLY, SUCH AS HIGH

*F.R. DIV.6   TEXAS   STP 95(208)UM   ETC   SHEET

TOM GREEN   COUNTY * HWY US 67   *CONT   77-6-67,ETC

GENERAL NOTES AND SPECIFICATION DATA--

HIGH PERFORMANCE CONCRETE (HPC) CONT'D

STRENGTH AGGREGATES FOR THE BEAMS, MAY BE REQUIRED TO MEET THE HPC SPECIFICATIONS.

LABORATORY AND FIELD TESTING

DURING THE TRIAL MIX PHASE OF THE HPC MIX DESIGN, AND FOR CONTROL OF THE HPC DURING FABRICATION/CONSTRUCTION, HPC SPECIMENS IN ADDITION TO THOSE REQUIRED BY THE SPECIFICATIONS/CONTRACT PLANS WILL BE MADE BY THE RESEARCHERS AND/OR TXDOT PERSONNEL. THE CONTRACTOR SHALL MAKE THE NECESSARY PROVISIONS TO ALLOW ADEQUATE SAMPLING OF THE HPC.

"SPECIAL STEEL" FOR DECK REINFORCEMENT

THE TOP MAT OF DECK REINFORCEMENT IN THE SECOND AND THIRD SPANS OF BOTH THE EASTBOUND AND THE WESTBOUND MAINLANES OF THE NORTH CONCHO RIVER, U.S. 87 & S.O. RR OVERPASS SHALL BE A "SPECIAL STEEL." THE "SPECIAL STEEL" IN THE WESTBOUND MAINLANES SHALL BE EPOXY COATED IN ACCORDANCE _ WITH ITEM 440, "REINFORCING STEEL."

THE "SPECIAL STEEL" CONFORMS TO ASTM A615, WITH A MINIMUM "RELATIVE RIB AREA" OF 0.12. THE "RELATIVE RIB AREA" IS THE RATIO OF BEARING AREA OF RIBS TO SHEARING AREA BETWEEN RIBS. THIS 'SPECIAL STEEL" MAY BE OBTAINED FROM CHAPARRAL STEEL CO. OF MIDLOTHIAN, TEXAS, AND BIRMINGHAM STEEL CO. OF BIRMINGHAM, ALABAMA.

PAVING ADJACENT TO HPC BRIDGE

THE LAST 100 FT OF ROADWAY PAVING ADJACENT TO THE BRIDGE ENDS SHOULD NOT BE PLACED UNTIL THE BRIDGE DECK IS CONSTRUCTED. THIS WILL PERMIT ADJUSTMENT OF VERTICAL CURVE, TO PREVENT EXCESSIVE SLAB THICKNESS, SHOULD ANTICIPATED BEAM CAMBER NOT BE ATTAINED.

STRUCTURE MONITORING

THE RESEARCHERS WILL DEVELOP A FIELD MEASURING PROGRAM TO MONITOR THE STRUCTURAL PERFORMANCE OF THE BRIDGE AND ITS COMPONENTS. THE CONTRACTOR WILL MAKE AVAILABLE SELECTED COMPONENTS TO PROVIDE ACCESS TO VARIOUS LOCATIONS TO ALLOW RESEARCHERS TO ATTACH MONITORING DEVICES.
IT IS ANTICIPATED THAT THE INSTALLATION OF EQUIPMENT OR THE COLLECTION OF DATA WILL NOT CAUSE ANY SIGNIFICANT DELAYS OR WORK STOPPAGES FOR THE CONTRACTOR.

INSTRUMENTATION SHALL BE PLACED IN THE EASTBOUND MAINLANES, AND IN SPAN NO. 1 ONLY OF THE WESTBOUND MAINLANES.

SPECIFICATION DATA

SHEET J

SPECIAL PROVISIONS

TO

ITEM 420

CONCRETE STRUCTURES

For this project, Item 420, "Concrete Structures", of the Standard Specifications, is hereby amended with respect to the clauses cited below and no other clauses or requirements of this Item are waived or changed hereby.

Article 420.3. General Requirements. The first paragraph is voided and replaced by the following:

> Before starting work, the Contractor shall fully inform the Engineer of the construction methods he proposes to use, the adequacy of which shall be subject to the approval of the Engineer. The researchers shall be provided access to the work, and will install the instrumentation. Any necessary facilities for installing and protecting instrumentation and equipment shall be provided by the Contractor.

Article 420.25. Payment. The last paragraph is supplemented by the following:

> Any HPC concrete that fails to meet required strengths shall not be subject to the penalties shown above.

SPECIAL PROVISIONS

TO

ITEM 421

PORTLAND CEMENT CONCRETE

For this project, Item 421, "Portland Cement Concrete", of the Standard Specifications, is hereby amended with respect to the clauses cited below and no other clauses or requirements of this item are waived or changed hereby.

Article 421.2. Materials, Subarticle (2) Fly Ash. The second paragraph is voided and replaced by the following:

The Contractor shall have the option of replacing a percentage of the required cement with fly ash, on a one to one basis by absolute volume, in accordance with the following:

When aggregate sources have not been identified as potentially reactive, the Contractor may substitute up to 35 percent of the cement with fly ash.

When potentially reactive aggregates are used, the Contractor may substitute from a minimum of 20 percent to a maximum of 35 percent of the cement with fly ash.

Only Type A fly ash may be used when Type II cement is specified.

No fly ash will be permitted when a white portland cement is required and no additional fly ash will be permitted when a Type IP cement is used.

Article 421.2. Materials, Subarticle (4) Coarse Aggregate. The first sentence of the first paragraph is voided and replaced by the following:

Coarse aggregate shall consist of durable particles of gravel, crushed blast furnace slag, recycled crushed portland cement concrete, crushed stone, or combinations thereof and shall be free from frozen material or injurious amounts of salt, alkali, vegetable matter, or other objectionable material.

Article 421.2. Materials, Subarticle (5) Fine Aggregate. The first and second paragraphs are voided and replaced by the following:

Fine aggregate shall consist of clean, hard, durable particles of natural or manufactured sand or a combination thereof, with or without a mineral filler. Fine aggregate shall be free from frozen material or

injurious amounts of salt, alkali, vegetable matter or other objectional material and shall not contain more than 0.5 percent clay lumps by weight.

When fine aggregate is subjected to the color test for organic impurities in accordance with Test Method Tex-408-A, the test result shall not show a color darker than standard.

When white portland cement is specified, the fine aggregate shall be light colored.

Unless otherwise shown on the plans, the acid insoluble residue of fine aggregate used in concrete subjected to direct traffic shall not be less than 60 percent by weight when tested in accordance with Test Method Tex-612-J.

Unless otherwise shown on the plans, fine aggregates may be blended to meet the acid insoluble residue requirements. When blended, the following equation will be used:

Acid Insoluble (%) = {(Al)(Pl+(A2)(P2)}1/100

where:

Al = acid insoluble (%) of aggregate 1
A2 = acid insoluble (%) of aggregate 2
Pl = percent by weight of Al of the fine aggregate blend
P2 = percent by weight of A2 of the fine aggregate blend

Article 421.2. Materials. Subarticle (5) Last paragraph is supplemented by the following:

For class K (HPC) concrete, the fineness modulus shall be between 2.30 and 3.10 as determined by Test Method Tex-402-A.

Article 421.8. Classification and Mix Design. The first paragraph is voided and replaced by the following:

The Contractor shall furnish the mix design, using a coarse aggregate factor acceptable to the Engineer, for the class(es) of concrete specified, to conform with the requirements contained herein and in accordance with Construction Bulletin C-11. The researchers will provide technical expertise to the Contractor in developing and evaluating the hPC mix designs. The Contractor shall bear the expense of providing adequate quantities of the HPC constituents, to the research facility located in Austin, Texas, necessary for developing the HPC mix designs. The Contractor shall perform, at his entire expense, the work required to substantiate the design, including several 4-5 cubic yard test batches or sections of each component, except that casting and testing of strength specimens will be done by the Department. Complete concrete design data shall be submitted to the Engineer for approval.

Article 421.8. Classification and Mix Design. The eleventh (11) paragraph is supplemented by the following:

The type of admixtures utilized in the high performance concrete (HPC) shall be designated by the researchers and may preclude the requirements of the Item 437, "Admixtures".

Article 421.8. Classification and Mix Design. "Table 3, Slump Requirements", A. Structural Concrete is supplemented by the following:

(9) High strength concrete (f'c >/= 9000 psi)	-----	Maximum slump may exceed 8" when approved by the Engineer

Article 421.9. Quality of Concrete. The third paragraph is voided and replaced by the following:

Unless otherwise shown on the plans the Contractor shall furnish and properly maintain all test molds. The test molds shall meet the requirements of Test Methods Tex-418-A and Tex-448-A and, in the opinion of the Engineer, must be satisfactory for use at the time of use. For high performance concrete (HPC), extra concrete and specimen molds may be required for making research test specimens. All compressive strength specimen molds for high strength concrete (f'c >/= 9000 psi) shall be 4" diameter by 8" in dimension, and shall have unbonded capping systems capable of attaining 15,000 psi, or caps made of high strength capping compound capable of attaining 15,000 psi. In addition, the Contractor shall be responsible for furnishing personnel to remove the test specimens from the molds and transport them, as needed, to the proper curing location at the schedule designated by the Engineer and in accordance with the governing specification. For all concrete items the Contractor shall have a wheelbarrow, or other container acceptable to the Engineer, available to use in the sampling of the concrete. The Contractor is responsible for disposing of used, broken test specimens.

Article 421-9. Quality of Concrete. "Table 4, Classes of Concrete", is supplemented by the following:

Class Of Conc.	Cement Per C.Y. Min. (Sacks)	Min. Comp. Sgth.(f'c) 28 Day psi (e)	Min. Flex. Sgth. 7 day psi	Max. Water Cement Ratio Gal/sk	Coarse Aggr. Grade No.	General Usage
K (HPC)	6.5	As specified on the plans	N.A.	5.0	3-4-5-6	For cast-in-place concrete deck, caps & columns of Eastbound Mainlanes (f)
H (HPC)	6.0	As specified on the plans	N.A.	5.5	3-4-5-6	For beams of Eastbound Mainlanes and prestressed concrete panels of Eastbound & Westbound Mainlanes (f) Also for beams of Entrance Ramp E
S (HPC)	6.5	4000	570 525 (c)	5.0	2-3-4-5	For cast-in-place deck of Westbound Mainlanes (f)

(e) For high strength concrete (f'c >/= 9000 psi) the 56-day minimum compressive strength shall be as specified on the plans.

(f) The North Concho River, U.S. 87 & S.O. RR Overpass.

SPECIAL PROVISIONS

TO

ITEM 424

PRECAST CONCRETE STRUCTURES (FABRICATION)

For this project, Item 424, "Precast Concrete Structures (Fabrication)", of the Standard Specifications, is hereby amended with respect to the clauses cited below and no other clauses or requirements of this Item are waived or changed hereby.

Article 424.3. General. Subarticle (1) is supplemented by the following:

(c). The researchers shall be provided access to the work, and will install the instrumentation. Any necessary facilities for installing and protecting instrumentation and equipment shall be provided by the Contractor.

Article 424-4. Fabrication. Subarticle (3) Paragraph 2 is voided and replaced by the following:

The control of concrete shall be by compressive tests of cylinders. For prestressed and nonstressed members, the making, curing, and testing of all required cylinder test specimens for release or handling strength or design strength shall be in accordance with Test Method Tex-704-I. The control of high strength concrete (f'c >/= 9000 psi) shall be by 56-day compressive strength testing. Job control testing may be performed at any age equal to or greater than 7 days; however, the minimum strength requirements for job control testing shall be 100 percent of the specified 56-day compressive strength. When the required 56-day compressive strength is not attained by job control testing, the final set of compressive strength specimens shall be tested at 56 days.

Article 424.4. Fabrication. Subarticle (4)(a) Last paragraph is voided and replaced by the following:

Protection shall be provided to maintain the temperature of the concrete at all surfaces of prestressed members at 50 F or above until "Release Strength" is reached. All concrete surfaces of nonstressed members shall be maintained at 40 F or above during the specified curing period. Protection shall consist of providing additional covering and, if necessary, supplementing such covering with artifical heating. When weather conditions indicate the possibility of the need for such temperature protection, all necessary heating equipment and covering material shall be on hand ready for use before permission is granted by the Engineer to begin placement of concrete. For high strength concrete (f'c >/= 9000 psi) protective measures shall be taken to assure the difference between the air temperature and the surface of the concrete shall not exceed 40 degrees F except during form removal.

Article 424.4. Fabrication. Subarticle (6) Paragraph 1 is voided and replaced by the following:

Careful attention shall be given to the proper curing of concrete. For high performance concrete (HPC), modifications to the curing requirements shall be made as required by the researchers. Prior to placing concrete, the Contractor shall submit the proposed curing methods and procedures to the Engineer for approval. Elevated temperature curing facilities shall be tested for a minimum of 48 hours prior to approval. Approved equipment and materials for curing shall be available for use prior to casting.

Article 424.4. Fabrication. Is supplemented by the following:

(7) Strand Pull-out Tests. Strand pull-out tests shall be performed by and at the expense of the Contractor. The making, curing, and testing of the strand pull-out test specimens shall be performed as directed by the researchers and as described herein.

(a) Strand pull-out test specimens and compressive strength cylinders shall be made in conjunction with 14 beams.

(b) The strand samples will be identified by the researchers.

(c) For the pull-out test procedure and any additional information regarding this procedure, call the TXDOT Design Division, Bridge Section, at 512-416-2268.

Article 424.5. Workmanship, Subarticle (2) Tolerances, Section (a) Prestressed Members. Table 1 is voided and replaced by the following:

TABLE 1
ALLOWABLE TOLERANCES

	Beams	Box Beams	Tees	Panels	Piling
Lengths (Normal to strands for panels)	+/-3/4"	+/-1"	+/-3/4"	+/-1/2"	-1"*
Width (Parallel to strands for panels	+3/4" -1/4"	+/-1/4"	+/-3/4"	+/-1/2"	+/-1/4"
Nominal Depth (Thickness in case of panels)	+1/2" -1/4"	+/-1/4"	+/-1/4"	+1/4" -1/8"	+/-1/4"

		Beams	Box Beams	Tees	Panels	Piling
Thickness	Top Slab or Flange	+1/2" -1/4"	+/-1/2"	+/-1/4"	NA	NA
	Bottom Slab or Flange	+1/2" -1/4"	+/-1/2"	NA	NA	NA
	Web or Wall	+3/4" -1/4"	+/-1/2"	+/-1/4"	NA	NA
Horizontal Alignment (Upon Release of Stress) – Deviation from straightness of mating edge of panels.		+/-1/8" per 10' of length	+/-1/4"	+/-1/4"	+/-1/8"	+/-1/8" per 10' of length
Deviation of Ends from Shop Plan Dimension (Bearing edge in case of panels)	Horizontal Skew	+/-1/4"	+/-1/8" per 1' of width, 1/2"max	+/-1/8" per 1' of width	+/-1/2"	+/-1/8"
	Vertical Batter	+/-1/8" per 1' of depth	+/-1/8" per 1' of depth, 1/2"max	+/-1/8" per 1' of depth	NA	+/-1/8"
Notched End Area (for diaphragms)	Depth	+/-1/4"	+/-1/4"	+/-1/4"	NA	NA
	Length	+2" -1"	+2" -1"	+2" -1"	NA	NA
Bearing Surfaces	Perpendicular to Vertical Axis	+/-1/8"	NA	+/-1/16"	NA	NA
	Deviation from Plane	+/-1/16"	+/-1/8"	+/-1/16"	NA	NA
Anchor Hole Location	From End of Member	+3/4" -1/4"	+/-1/4"	+3/4" -1/4"	NA	NA
	Longitudinal Spacing	+/-3/4"	+/-1/2"	+/-3/4"	NA	NA
	Transverse Location	+/-1/4"	+/-1/4"	+/-1/4"	NA	NA
Diaphragm or Lateral Tie Location		+/-1/2"	+/-1/2"	+/-1/2"	NA	NA
Position of Void** (Longitudinal for Box Beams)		NA	+/-1"	NA	NA	+/-1/2"
Position of Strands		+/-1/4"	+/-1/4"	+/-1/4"	+/-1/8" vert. +/-1/2" Horiz.	+/-1/4"
Position of Hold-Down Points		+/-6"	+/-6"	+/-6"	NA	NA
Position of Handling Devices		+/-6"	+/-6"	+/-6"	NA	+/-6"

Measured for bottom of panel.
* Maximum length approved by the Engineer.
** Length of Box Beam Void Material +1"-6".

San Angelo Bridge
Properties of Cement used in Girders and Deck Panels

Property, %		
SiO_2		19.66
Al_2O_2		5.38
Fe_2O_3		2.06
CaO		64.05
MgO		1.26
SO_3		4.09
Loss of Ignition		2.64
Insoluble Residue		0.27
Free Lime		N/A
C_3S		60.58
C_3A		10.77
Total Alkali		0.60
Specific Surface, cm^2/gm		
Blaine		5730
Wagner		2926
% Passing No. 325 Sieve		98.6
Compressive Strength, psi		
1 Day		4545
3 Day		5910
7 Day		6750
28 Day		N/A
Setting Time, min		
Vicat	Initial	75
	Final	120
Gilmore	Initial	135
	Final	255

N/A = Not available